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G.F. Dionne

Fabrication of Metal Mirrors for Far-Infrared Wavelengths

7 October 1981

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LEXINGTON, MASSACHUSETTS

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Raymond L. Loiselle

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LINCOLN LABORATORY

FABRICATION OF METAL MIRRORS FOR FAR-INFRARED WAVELENGTHS

G.F. DIONNE

Group 33

TECHNICAL REPORT 588

7 OCTOBER 1981

LEXINGTON MASSACHUSETTS

ABSTRACT

A simple machining procedure has been applied successfully to produce metal mirrors suitable for far-infrared wavelengths. Ninety-degree off-axis paraboloidal or ellipsoidal mirror sections may be cut from brass or aluminum by means of a series of pre-determined increments on a conventional laboratory lathe. Paraboloidal mirrors with low f-numbers (f/2) have been used with good results as part of the collecting optics of a far-infrared heterodyne receiver.

In the far-infrared (FIR) region (wavelengths $\sim$ 0.5 mm), transmission usually involves a quasi-optical approach that guides the radiation by means of mirrors and lenses. Conventional coaxial cable and waveguides so prevalent with microwaves are useless at these wavelengths because of fabrication difficulties and loss considerations. Since power sources in this region have limited strength (on the order of mW), even lenses with their 30 to 50 percent attenuation factors are seldom used when high-reflectivity mirror surfaces can perform the same function. As a result, many occasions arise where a small, fast ($\sim$ f/2) mirror tailored to a specific application can be of considerable value to the experimentalist. Unfortunately, mirrors with these low f-numbers are almost unavailable commercially at the present time. A unique method employing a milling machine for shaping metal mirror sections with contours approximated to the desired curve was recently reported by Erickson [1]. This note describes the application of a straightforward (though more tedious) laboratory method for making mirrors with exact contours that would otherwise be difficult to acquire even by more sophisticated techniques.

The fundamental principle of the mirror fabrication technique is based on the fact that both paraboloids and ellipsoids (or other shapes) are surfaces of revolution, the focal lengths and apertures of which may be defined precisely by the coefficients of their geometric equations. Consequently, equally spaced points lying on a cross-section curve through the axis of the particular surface may be computed directly and a set of x-y coordinates generated for use in machining the surface in a series of steps, as illustrated in Fig. 1.

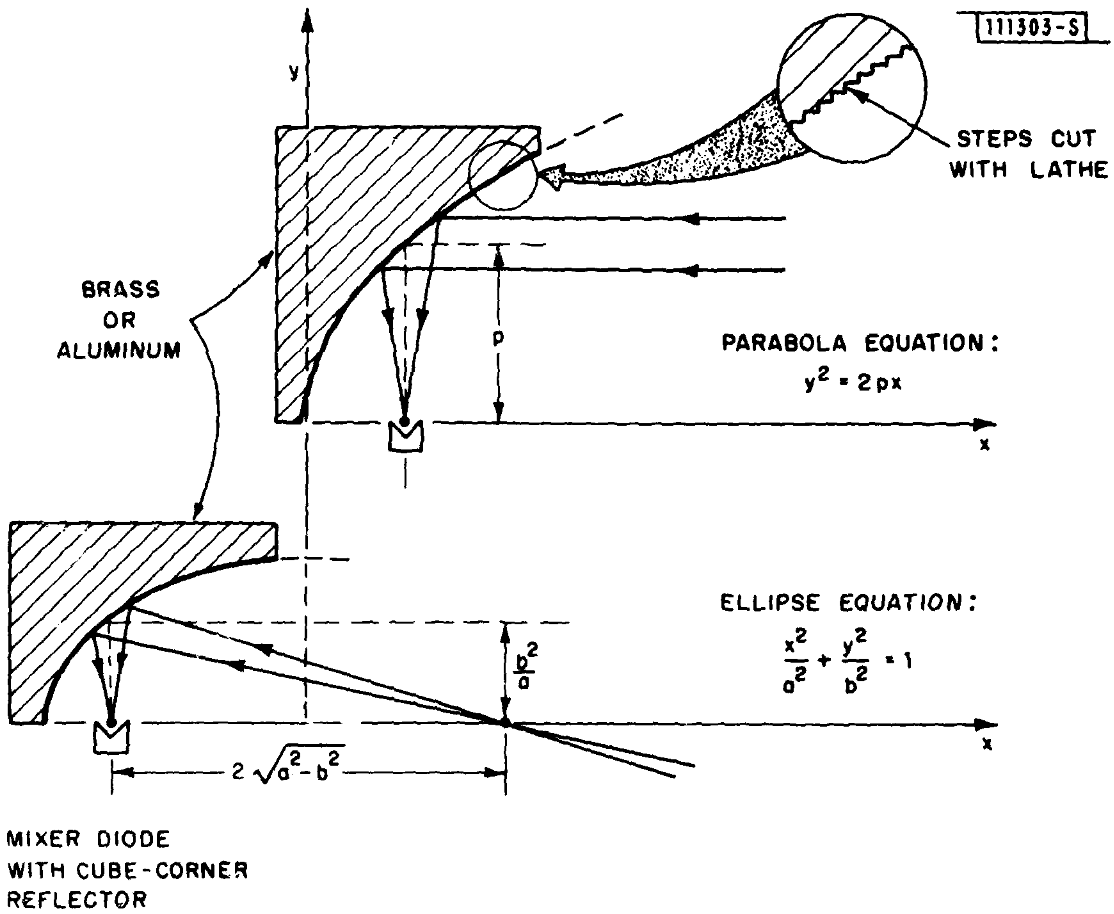

Fig. 1. Design schemes for digital machining of paraboloidal and ellipsoidal mirrors using a lathe for the incremental cutting.

With a cylindrical piece of brass or aluminum (which may have the excess material from the core already removed), the desired contour of the mirror was machined in increments as large as 0.5 mm on a lathe with precision of 0.025 mm. The above numbers were dictated by the general rule-of-thumb that increment sizes should not exceed the shortest wavelength of the intended application (although it is quite possible that larger steps may be used if the subsequent smoothing operations are carried out with sufficient care to preserve the exactness of the desired contour). Step sizes of one wavelength and one-half wavelength were used with equivalent results. Although requiring care and patience of the operator in executing as many as 100 steps, the method is capable of producing several 90-degree off-axis sections from a single cylindrical block. From the 14-cm diameter, 4-cm thick brass cylinder shown in Fig. 2, eight mirror sections of 2.5-cm aperture and 5-cm focal length may be obtained.

With the material still rotating on the lathe, the surface was smoothed by hand polishing with progressively finer grades of sanding cloth and paper until all traces of the machined ridges were no longer visible. Finally, a jeweller's rouge polishing compound used with a buffing wheel attached to a drill press provided the final surface finish. This last stage produced better results when carried out on the individual pieces rather than the entire cylindrical section. A typical mirror finish (see Fig. 3) was found to be on the order of 0.1 μm by means of a surface profilometer.

In one successful application, a paraboloidal mirror section was used to focus far-field radiation from a 10-cm diameter blackbody source onto a Schottky diode used as a mixer in a FIR heterodyne radiometer [2] (see Fig. 4). Since

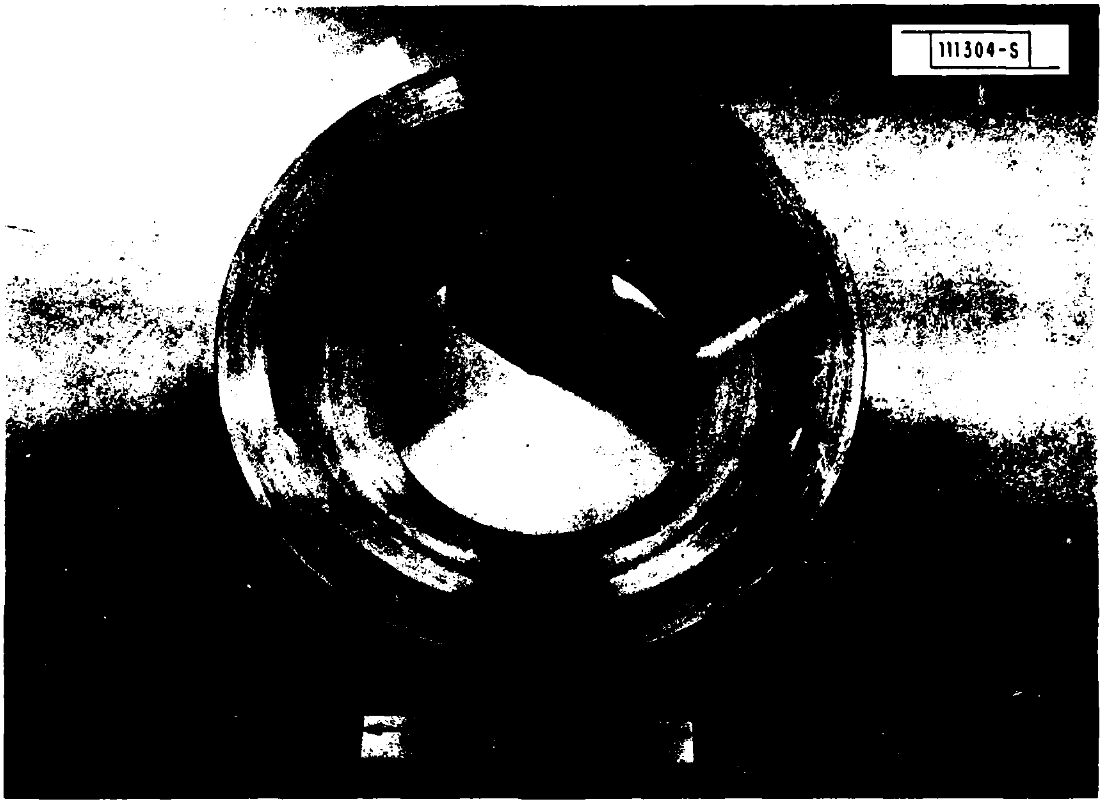

Fig. 2. Photograph of metal cylinder after completion of the step-by-step cutting (in 0.5 mm steps) of the pre-calculated mirror surface. Core of material was removed initially to reduce operating time of the lathe.

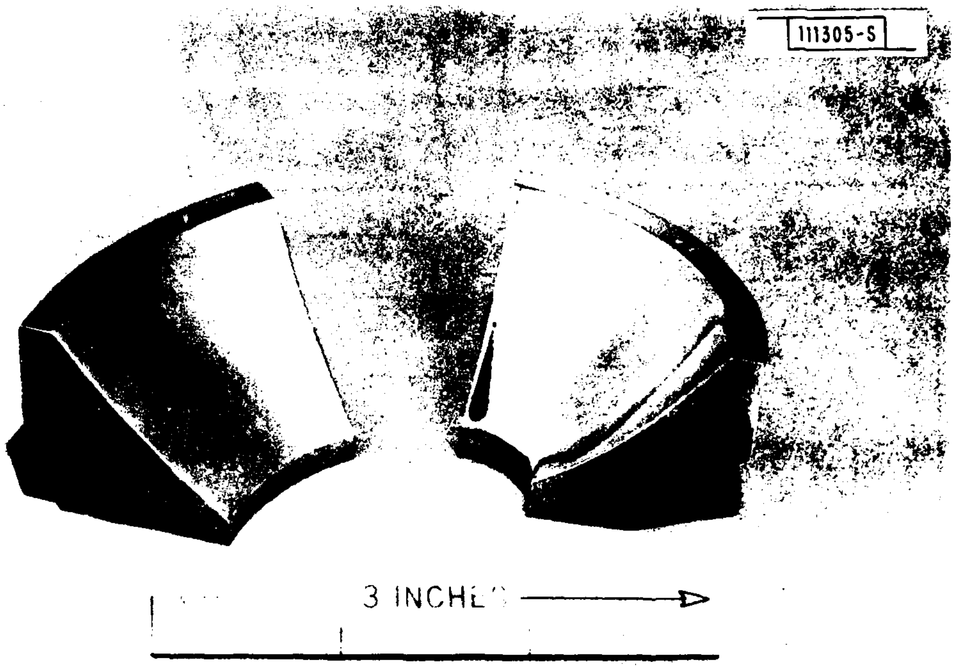

Fig. 3. Photograph of finished f/2 paraboloidal 90-degree off-axis mirror sections; left, a 5-cm focal distance with a 2.5-cm aperture; right, a 2.5-cm focal length with a 2.5-cm aperture.

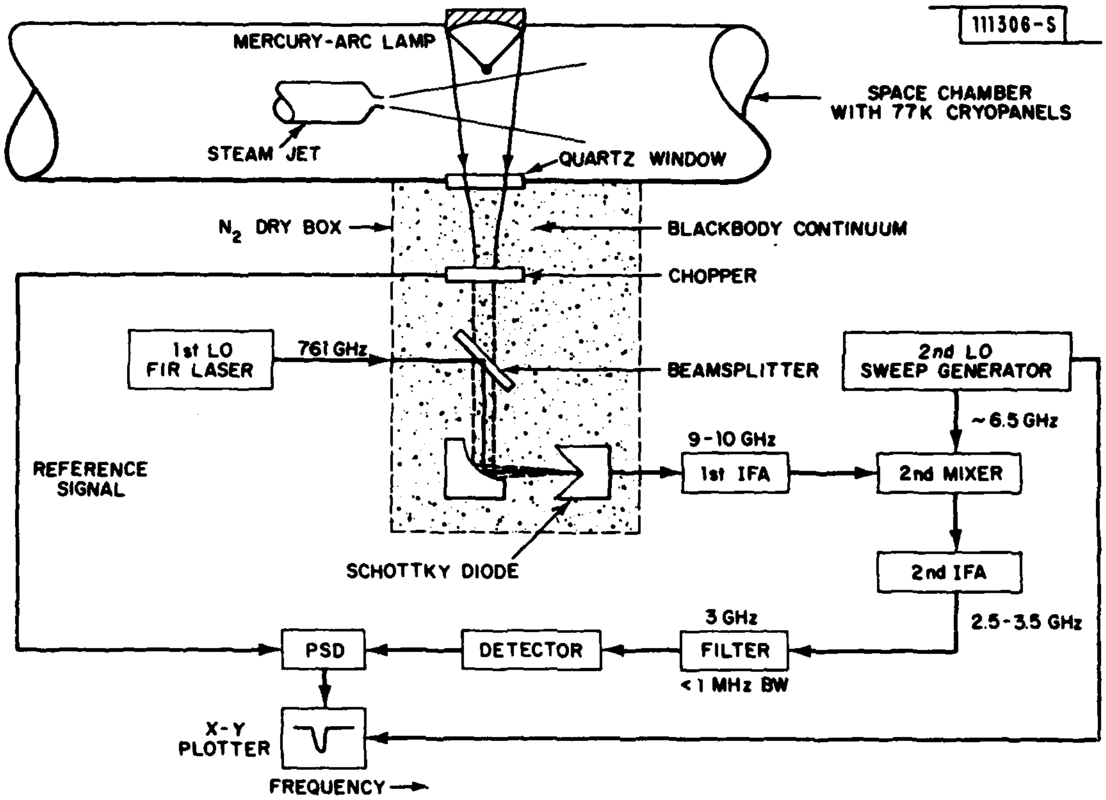

Fig. 4. Block diagram of two-stage heterodyne radiometer for detecting the 752-GHz H_2O rotational line in a laboratory jet operating in a high-vacuum space chamber.

the beam of the paraboloid was filled by the blackbody up to a distance of 5 meters, it was concluded that the beam width conformed to the theoretical diffraction width $\lambda/D \simeq 1/50$ radians, where λ is the wavelength ($\simeq$ 0.5 mm) and D is the mirror aperture (25 mm). With this beamwidth, the calculated beam diameter at 5 meters ($\simeq 5\ \lambda/D$) matched the 10-cm diameter of the source (see Fig. 5), verifying that the accuracy of the mirror was sufficient for applications at one-half millimeter wavelength. With a precision metallized-glass mirror of similar dimensions used in the same application, the experimental results did not improve in comparison with those cited above.

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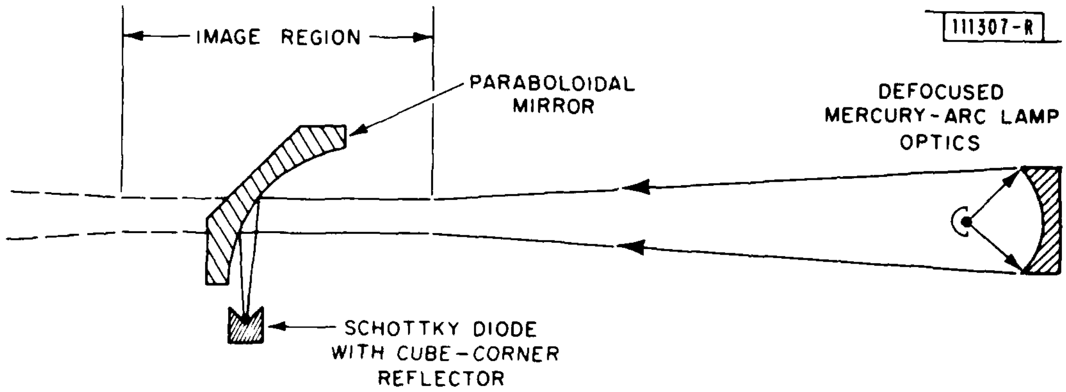

Fig. 5. Optical arrangement for mercury-arc blackbody, off-axis paraboloidal mirror section, and Schottky diode detector used in FIR radiometer experiments. Beamwidth of paraboloidal antenna is filled by the blackbody source and conforms to the theoretical diffraction-limited conditions at 0.5 mm wavelength.

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2. G. F. Dionne, J. F. Fitzgerald, T-S. Chang, M. M. Litvak, and H. R. Fetterman, Intl. J. Infrared and Millimeter Waves 1, 581 (1980).

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